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Büsnau biorefinery

KoalAplan: municipal wastewater as a source of recyclable materials

Our wastewater not only contains dirt and excretions, but is also rich in carbon, nitrogen and phosphorus, which can be recovered. A sewage plant can thus become a source of raw materials. In the KoalAplan project, a new type of biorefinery will be used to convert the carbon recovered from wastewater into sustainable products.

The ERDF Bioeconomy – Bio-Ab-Cycling funding programme is about using bioinspired processes in modular biorefineries to recover valuable raw materials from waste and wastewater and return them to a sustainable circular economy. The Baden-Württemberg Ministry for the Environment, Climate and Energy Management, together with the European Regional Development Fund (ERDF), is funding five projects with a total of 19 million euros. These projects aim at gathering experience in pilot plants under real conditions in order to find out what can be turned into reality on the large scale. The goal is to make companies aware of the potential of bioeconomic strategies and motivate them to reduce or replace fossil raw materials in return for potential cost savings and the development of new products to market.

KoalAplan: recycling of carbon and nitrogen

Prof. Dr Harald Horn is the coordinator of the KoalAplan project, which aims to recover substances such as ammonium and carbon from municipal wastewater.

Municipal wastewater is rich in raw materials, and recovering them makes a positive contribution to climate neutrality, as the products obtained replace petroleum-based raw materials and also produce fewer climate-damaging gases. The KoalAplan project expands the functional scope of the University of Stuttgart’s Büsnau Treatment Plant for Teaching and Research to include the recovery of recyclable materials. The project is funded with a total of 2.3 million euros.

Prof. Dr. Harald Horn, head of the DVWG Research Unit (German Gas and Water Association) at the Engler-Bunte Institute of the Karlsruhe Institute of Technology (KIT) and coordinator of the KoalAplan project, wants to show that it is possible to extract nitrogen, hydrogen and carbon from wastewater using biological and technical processes in order to make products such as fertiliser and bioplastics. KoalAplan will focus primarily on carbon. "For me, it is an opportunity to show that wastewater treatment in Germany has the potential to deal with organic carbon differently than it has done before and to create value," he says. Biomass and climate-relevant carbon dioxide (CO_2) are normally produced from the organic carbon as it passes through a sewage treatment plant. The use of carbon dioxide for making fertiliser and other things would be significantly more sustainable. Another of the project’s aims is the recovery of ammonium from the particle-free main wastewater stream. In the long term, the pilot project is designed to be implemented on a large scale.

Büsnau biorefinery as living lab

The University of Stuttgart operates a municipal wastewater treatment plant, which is affiliated with the Institute for Sanitary Engineering, Water Quality and Waste Management in Büsnau. The plant is used for research into wastewater treatment, and simultaneously treats the wastewater of 10,000 inhabitants of a city district. A partial stream of this municipal wastewater passes through the pilot plant. This is currently being set up and initial results are expected in a year's time. One difficulty will be to enrich the organic carbon to a high enough concentration so that value creation can be achieved. "The substances are present in a very diluted form due to the amount of water we use to transport our wastewater in water-borne sewer systems," Horn explains. "This is highly unfavourable for recovering valuable substances."

Badge made of biodegradable plastic, as will be produced from carbon recovery when the KoalAplan plant starts operating (the one shown here is produced by Veolia).
© Prof. Dr. Harald Horn, KIT Karlsruhe

Another dilemma lies in the removal of nitrogen from wastewater, as this requires the organic carbon that would be preferable to extract as a valuable material in the biorefinery. Biological nitrogen removal in sewage treatment plants is normally carried out by various microorganisms, initially by the bacterial group of nitrifiers that oxidises ammonium to nitrate with the help of atmospheric oxygen, which the bacterial group of denitrificants then ultimately reduces to gaseous nitrogen (N_2) with the help of organic carbon as a reducing agent. N_2 then escapes unused into the atmosphere. The researchers in Büsnau are therefore investigating how denitrification can be circumvented and how the organic carbon can be specifically removed from the wastewater. "We are reaching our limits with carbon, as it is mostly present in particulate form, i.e., as a solid," says the chemical engineer. In this case, process engineering becomes the decisive factor.

Microsieve at the heart of the project

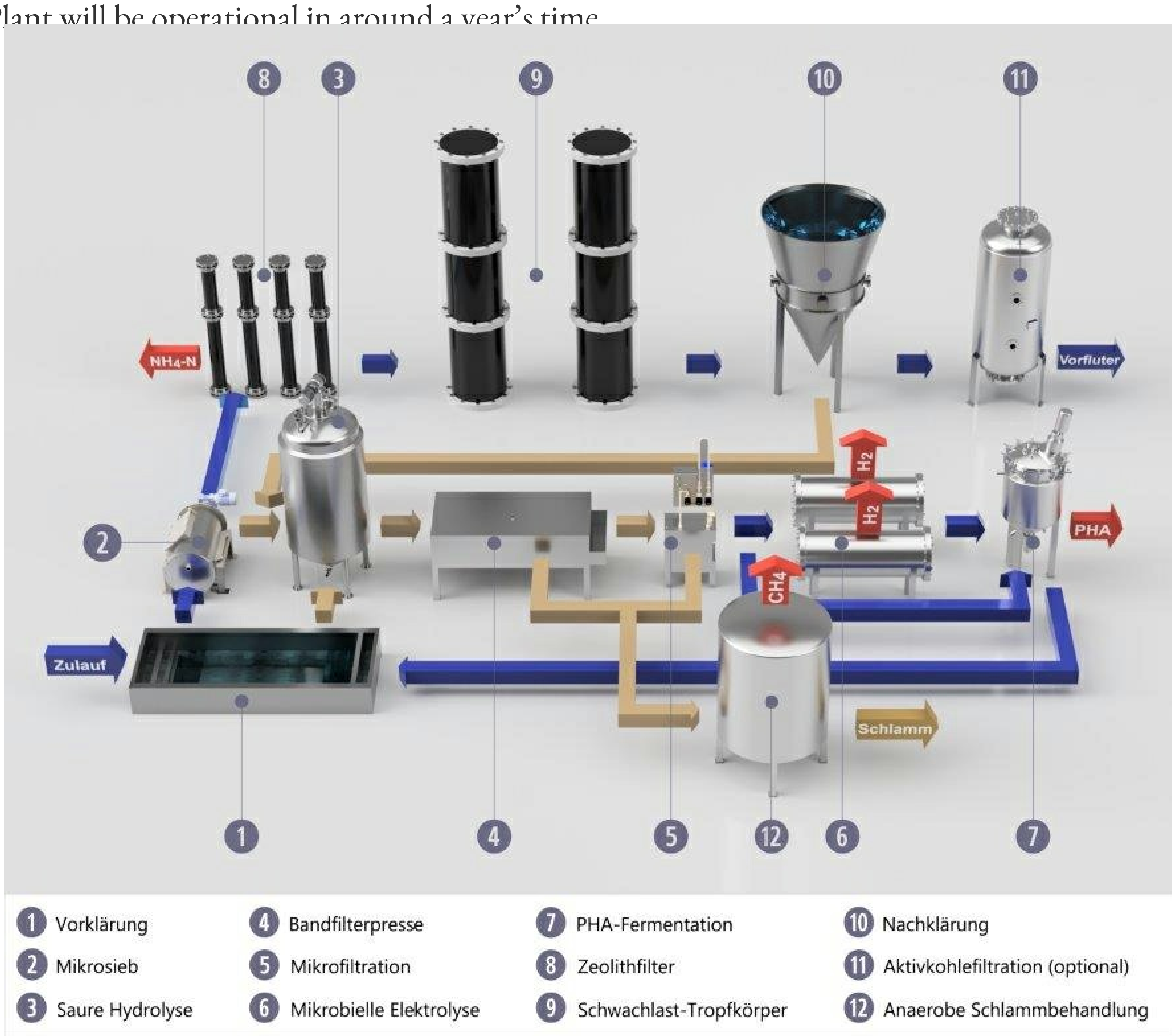
During primary sedimentation (1), the first step involves mechanical purification to trap coarse substances that end up in our toilets (see process flow diagram). Here, a third of the organic carbon is separated. Afterwards, a microsieve (2) is used as an additional component in the side stream of the new biorefinery. This is the core of the KoalAplan idea. This sieve separates another third of the particulate carbon by retaining very fine particles. "The carbon is then very concentrated, in the grammes per litre range, which is suitable for use in biotechnology," says Horn.

The next process step in the biorefinery is acid hydrolysis (3), in which the diverted organic carbon compounds are broken down into organic acids by microorganisms. These acids are much higher-value products than, for example, methane, which is currently produced in sewage treatment plants from the organic carbon in digestion towers and converted into electricity with gas engines. "The organic acids are basic building blocks for a wide variety of products," says Horn.

The hydrolysate, which is rich in organic acids, is then passed through a filtration unit (4) and a microfiltration unit (5) and subsequently subjected to microbial electrolysis (6) in a novel reactor system. "We envisage two further functional steps for KoalAPlan," says the researcher. "One is the production of hydrogen during microbial electrolysis, whereby the electricity required in the process would come from the material conversion itself." In the bioelectrochemical system, microorganisms decompose the acids to CO_2 and electrons at the anode, and biohydrogen is formed at the cathode with the protons produced. Biohydrogen can be used as an energy source or synthesis gas. The remaining organic acids are fed into a fermenter (7), where they are in turn converted by microorganisms into polyhydroxyalkanoate (PHA), a very solid, degradable biopolymer for which various applications are conceivable. "A very attractive substitute for plastics obtained from petroleum," says Horn.

After microsieving, the ammonium in the mainstream is fed directly into a zeolite filter (8), which acts as an ion exchanger, in order to remove the nitrogen without the intervention of the carbon. The nitrogen can then still be turned into a useful product. The ammonium is removed without being biologically converted. The regeneration of the filter enables the recovery of ammonium, which can be used directly as a fertiliser in agriculture. Furthermore, the wastewater in the mainstream goes the way it usually does in a traditional wastewater treatment plant: the wastewater passes first through a low-load trickling filter (9) to break down remaining nitrogen and carbon before it continues on to a secondary sedimentation tank (10) and anaerobic sludge treatment (12), where all sludge produced ends up and methane is recovered. Activated carbon filtration (11) is an additional treatment option.

Plant will be operational in around a year's time



Process steps in the University of Stuttgart's Büsnau pilot plant: steps 2 to 7 take place in the actual biorefinery, which treats 2 percent of the volume stream. The rest of the wastewater (98 percent) runs in the mainstream through steps 2 and 8 to 12 (see text for details).

The KoalAplan project runs from end of October 2021 to April 2024, and the schedule is tight. Some components have already been built and are functioning. Others, such as the 100-litre microbial electrolysis reactor, take longer to implement because they do not yet exist in the required form and have to be manufactured in the Engler-Bunte Institute's workshop. The feasibility study on the use of the hydrogen produced is also still pending, as is the evaluation of the plant's electricity consumption. It remains to be tested whether the CO_2 footprint is actually better than that of a conventional sewage treatment plant. "All this still has to happen before we will be able to decide whether it is a process for the future," says Horn, but he remains confident.

Other project partners:
In addition to DVGW, other project partners are: the University of Stuttgart (Treatment Plant for Teaching and Research), the Hamburg University of Technology, the Fraunhofer Institute for Interfacial Engineering and Biotechnology (IGB), the Clausthal University of Technology (assessment of CO_2 footprint) and the Baden-Württemberg State Agency for Environmental Technology and Resource Efficiency as well as the University of Southampton, UK (external consultant).

Article

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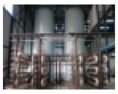

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